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EFFECT OF LOSS OF VALLEY STORAGE IN THE CANNELTON POOL ON OHIO RIVER FLOOD HEIGHTS

by

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A mathematical model called SOCHMJ (Simulation of Open Channel Hydraulics in Multi-Junction Systems) ~~has been employed~~ was used to determine the effect of valley storage loss in the Cannelton Pool on flood heights along the Ohio River. Three levels of storage loss have been investigated. The first level was the complete removal of valley storage and was accomplished by assuming the placement of levees along the banks throughout the Cannelton Pool. The second level of storage loss was arrived at through ~~the~~ placement of levees halfway from the

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bank to the maximum lateral encroachment of the 1945 flood throughout the Cannelton Pool. The third level consisted of assuming levees along the bank of the lower 58 miles of the Cannelton Pool. For each of the first two levels of storage loss, the calibrated values of Manning's n throughout the Cannelton Pool were first increased and then decreased by 20% ~~percent~~ to determine the effect on flood heights of varying the roughness coefficient. It is concluded that,

It was concluded from the model results that neither a complete loss of valley storage nor substantial variation of Manning's n in the Cannelton Pool appreciably influenced flood heights as far downstream as Evansville, Indiana. However, during the calibration of the model to the 1945 flood, a rather crude approximation to the geometric data was required in areas where substantial flows cut across river bends. Therefore, before ~~the initialization of~~ initiating major floodplain encroachment in the Cannelton Pool, additional studies with a much more elaborate treatment of the flows cutting across major river bends should be undertaken.

PREFACE

The work described herein and the preparation of this report were conducted during the period December 1976 to June 1977 for the U. S. Army Engineer Division, Ohio River (ORD), by the U. S. Army Engineer Waterways Experiment Station (WES) under the general supervision of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, and M. B. Boyd, Chief of the Mathematical Hydraulics Division (MHD).

Dr. B. H. Johnson, MHD, and Mr. P. K. Senter of the Automatic Data Processing Center conducted the study and prepared the report. Mr. Ron Yates of the Reservoir Control Center of ORD aided in the data collection and was instrumental in guiding the study to completion.

Director of WES during the conduct of this study and the preparation and publication of this report was COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
acre-feet per mile	1233.482	cubic metres per kilometre
cubic feet per second	0.2831685	cubic metres per second

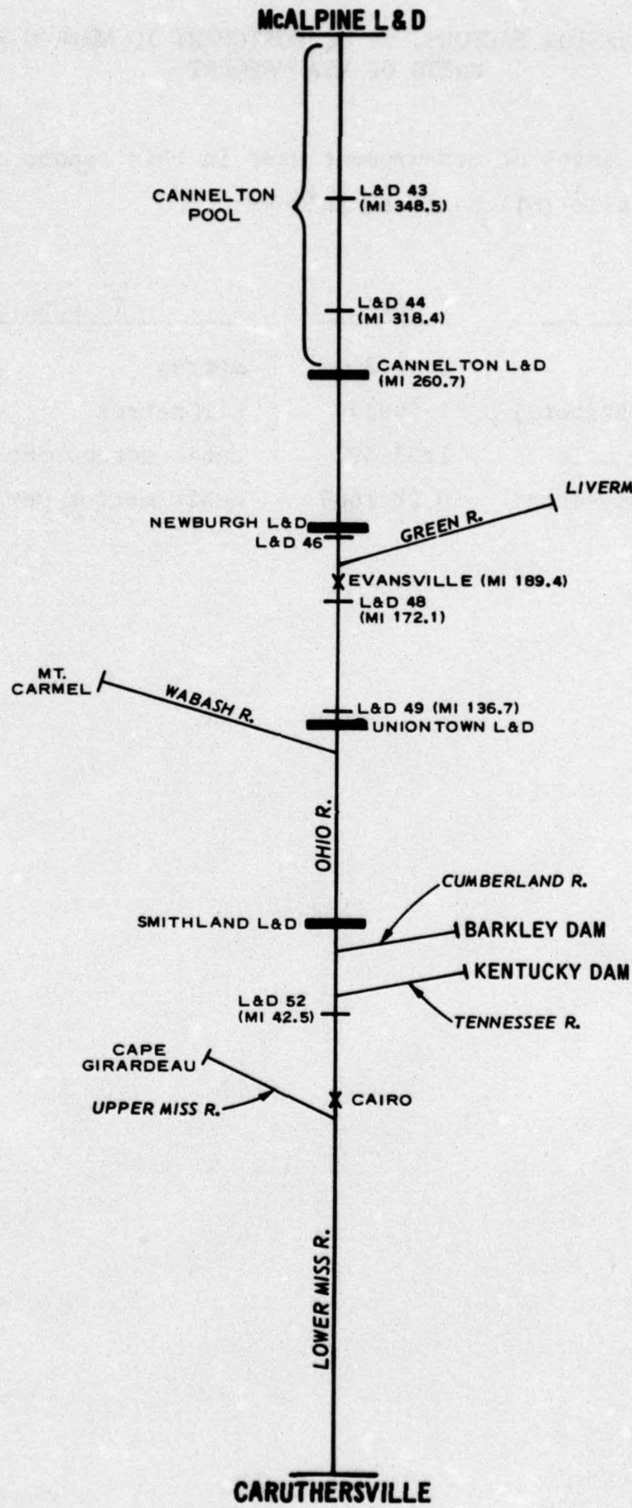

Figure 1. Physical limits of system

EFFECT OF LOSS OF VALLEY STORAGE IN THE CANNELTON POOL ON OHIO RIVER FLOOD HEIGHTS

PART I: INTRODUCTION

1. Open-channel unsteady flows such as flood waves in rivers are controlled by inertial effects, frictional effects and the mechanism of storage in both the channel and the adjacent valley. A common problem that frequently must be addressed by floodplain management groups is the quantitative determination of the effect on flood waves of encroachment upon the floodplain; i.e., loss of valley storage.

2. In a letter dated 1 December 1976, the U. S. Army Engineer Division, Ohio River (ORD), requested the Mathematical Hydraulics Division (MHD) of the U. S. Army Engineer Waterways Experiment Station (WES) to conduct a study to determine the effect of a loss of valley storage in the Cannelton Pool on flood heights at downstream locations along the Ohio River, in particular at Evansville, Indiana.

3. To accomplish this task, the *ORD-WES open-channel unsteady* flow model (SOCHMJ) was employed. The first phase of the investigation consisted of calibrating the numerical model to the 1945 Ohio River flood. The physical limits of the system modeled extend from McAlpine Lock and Dam on the Ohio River; Livermore, Kentucky, on the Green River; Mt. Carmel, Indiana, on the Wabash River; Barkley Dam on the Cumberland River; Kentucky Dam on the Tennessee River; and Cape Girardeau, Missouri, on the Upper Mississippi River, to Caruthersville, Missouri, on the Lower Mississippi River. Figure 1 is a schematic of the above system.

4. In the second phase of the study the calibrated model was again applied to the 1945 flood but with assumed levels of storage loss in the Cannelton Pool. The first level consisted of assuming levees were constructed along the channel throughout the Cannelton Pool reach, whereas the second level consisted of assuming the construction of levees halfway from the channel to the point of maximum encroachment of the 1945 flood upon the floodplain. For each level of storage loss,

two additional runs were made in which the calibrated values of Manning's n in the Cannelton Pool were first increased and then decreased by 20 percent. One additional run in which the loss of storage was assumed to occur only in the lower 58 miles* of the Cannelton Pool was made to determine whether the influence on flood heights is greater upstream or downstream of a reach in which valley storage has been removed.

5. A brief description of the numerical model employed is given before detailed discussion of results of model applications are presented.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

PART II: DISCUSSION OF NUMERICAL MODEL

Theoretical Aspects

6. The numerical model used to determine flood heights along the Ohio River is a model called SOCHMJ[1] (Simulation of Open Channel Hydraulics in Multi-Junction Systems). The development of SOCHMJ was based upon an earlier unsteady flow model developed by Garrison.[2] The equations governing open-channel unsteady flows are statements of the conservation of mass and momentum of the flow field and may be written as:

Continuity: $$\frac{\partial h}{\partial t} + \frac{1}{B}\frac{\partial (Av)}{\partial x} - \frac{q}{B} = 0$$

Momentum: $$\frac{\partial v}{\partial t} + v\frac{\partial v}{\partial x} + g\frac{\partial h}{\partial x} + \frac{qv}{A} + \frac{gn^2 v|v|}{2.21\, R^{4/3}} = 0$$

where

- h = water-surface elevation above mean sea level
- $\partial/\partial t$ = rate of change with respect to time
- B = width of water surface
- A = cross-sectional flow area
- v = mean flow velocity
- $\partial/\partial x$ = rate of change with respect to distance
- q = lateral inflow per unit distance along the channel per unit time
- g = acceleration due to gravity
- n = Manning's resistance coefficient
- R = hydraulic radius

These equations are often referred to as the equations of St. Venant. Since analytical solutions don't exist, numerical techniques such as finite differences must be employed. The centered explicit finite difference scheme developed by Stoker[3] under an ORD contract and employed in the Garrison model has also been utilized in SOCHMJ.

7. SOCHMJ can be applied to a system composed of an unlimited number of junctions and branches, including a system containing no tributaries, i.e. a single river. Also, the model can be applied to a system such as encountered in the flow around an island. In SOCHMJ, Manning's n is allowed to vary with elevation as well as with distance along the channel, whereas the Garrison code allows only for variation along the channel. Recent modifications to SOCHMJ include allowing for the effect of Cannelton, Newburgh, Uniontown, and Smithland Locks and Dams plus Lock and Dam 52.[4] The positions of these structures are shown in Figure 1 although it should be noted that they were not included in the 1945 computations presented herein.

8. As noted above, SOCHMJ can be applied to a system composed of many rivers, with each river labeled as a branch of the system. In the discretization of the physical system, a restriction on the number of Δx's per branch exists. A minimum of four Δx's must be contained within each branch with the additional restriction that if more than four exist, the total must be an even number. On each branch, all Δx's have an equal length; although the length can vary from one branch to another. In the earlier version of SOCHMJ the time step prescribed was common to all branches. Thus, since the stability criterion

$$\left(v + \sqrt{g \frac{A}{B}}\right)\frac{\Delta t}{\Delta x} \leq 1 - \frac{gn^2 |v| \Delta t}{2.21\ R^{4/3}}$$

must always be satisfied, it is obvious that the smallest Δx in the system determined the Δt to be used for computations on all branches. In the recent modifications to the model, this restriction has been relaxed somewhat by allowing for the specification of two time steps--a large time step for large branches and a small time step for small branches. Computations on small branches are made at small time step intervals within each large time step. Details are presented in Reference 4.

Input Requirements

9. The first group of input data required by SOCHMJ consists of basic information about the system being modeled such as the total number of junctions and branches, the total number of net points in the system, etc. The second group of data contains information about the stations at which output is desired. In addition to requesting output at particular stations, output can be requested at any of the net points of the system. The third group of data contains information about each branch such as the type of boundary condition prescribed, the size of the spatial step, etc. The fourth data group contains information about the junctions, e.g., the numbers of the branches associated with each junction. The most voluminous data group consists of the tables of geometric data. A table of top width, flow area, (hydraulic radius)$^{2/3}$, and Manning's n, all as functions of elevation, must be input at each net point of the system. The next data group consists of the initial values of the elevation and discharge at all grid points. The final data group required by SOCHMJ consists of the time-dependent boundary conditions which must be prescribed at each open boundary plus any lateral inflows. Due to the nature of the governing St. Venant equations, either elevations, discharges, or a table of discharges versus elevations may be specified as boundary conditions as long as the flow is subcritical.

Output Provided

10. Output can be obtained from SOCHMJ at specified stations or river miles as well as at all or specific net points. At such net points, output in the form of elevations, velocities, and discharges plus geometric data, if desired, is provided. At particular river mile locations where output is requested, similar information except for geometric data is printed. Output is provided after a certain interval of time, the value of which is variable and is specified in the input data.

PART III: CALIBRATION RESULTS

11. In the research effort described in Reference 4, SOCHMJ was set up for application to the physical system shown in Figure 1. The discretization of the system is presented in Table 1. For the purpose of the study described herein involving the effect on flood heights of loss of valley storage in the Cannelton Pool, ORD requested that the model be calibrated to the extremely large 1945 Ohio River flood. In this application, time-dependent elevations were prescribed at McAlpine Lock and Dam, Mt. Carmel, and Cape Girardeau, whereas discharges were specified at Livermore, and Barkley and Kentucky Dams. These boundary hydrographs are presented in Plates 1 and 2. The rating curve (discharges versus elevations) shown in Table 2 was the boundary condition prescribed at Caruthersville. Lateral inflows were input at various points in the system. A summation of these inflows for several reaches is presented in Plate 3. Again, it should be noted that Cannelton, Newburgh, and Uniontown Locks and Dams were not constructed in 1945 and thus were removed from the computations.

12. Calibration of the model consisted primarily of adjusting Manning's n throughout the system until computed and recorded elevations and discharges at several points agreed favorably. In the attempt to calibrate the model to the extremely large flood heights experienced in the 1945 flood, problems were encountered after about the first or second day of March. The computed elevation hydrographs at the major points of interest downstream of the Cannelton Pool, e.g., Evansville and Lock and Dam 48, could not be made to match the recorded results with reasonable variation of Manning's n nor with variation of the water-surface top width. Often the top width is extremely difficult to quantify at high elevations. For this reason, if a comparison of computed and recorded hydrographs justifies such action, a variation of the top width in complicated areas certainly seems warranted. After an inspection of hydrographic maps of the Ohio River plus consultation with

personnel* involved in the testing of the 1945 flood on the physical Mississippi Basin Model located in Clinton, Mississippi, it was concluded that during the 1945 flood a major portion of the flow probably cut across many of the bends in that reach of the Ohio River from just below Cannelton Lock and Dam to Lock and Dam 49. In the numerical model, this was reflected through a reduction in the size of the spatial step on branches 3, 4, 5, and 7. The river mileage removed and the resulting discretization of the system to be used from 1 March to the end of the simulation run on 18 March are presented in Tables 3 and 4. In addition to decreasing the spatial step, the cross-sectional flow areas in tables downstream of the Ohio's junction with the Green River were increased 25 percent at elevations near the top of the 1945 flood heights to approximate the greater flow areas across the bends. This relatively crude calibration procedure is considered reasonable for feasibility study purposes. However, a more rigorous treatment of these overbank flow situations may be desirable during the design phase of any proposed major floodplain encroachment.

13. Calibration results are presented in Plates 4 and 5 at Locks and Dams 43, 45, 46, and 48 and at Evansville. The computed results are given as two separate segments due to applying the model from 18 February to 1 March with the spatial steps shown in Table 1, whereas from 1 March to 18 March the spatial steps presented in Table 4 were prescribed. As shown in Plate 5, the computed elevations at Evansville are within about ±1.0 ft of the recorded values.

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* Personal communication with James E. Foster, Chief of the Mississippi Basin Model Section, WES.

PART IV: RESULTS FROM LOSS OF VALLEY STORAGE AND VARIATION OF THE ROUGHNESS COEFFICIENT IN THE CANNELTON POOL

Level 1 - Levees Constructed Along the Channel

14. In an attempt to assess the effect on flood heights of the complete loss of valley storage in the Cannelton Pool, runs were made with the water-surface top width fixed at the channel top width as the elevation increased beyond the elevation of the channel top. This is equivalent to the construction of levees along the channel. The same values for Manning's n as determined in the calibration phase were maintained.

15. The actual amount of storage removed in the computations depends upon the maximum flood heights experienced in the Cannelton Pool at each net point but can be approximated by computing the average channel top width and the average elevation at which this width occurs plus the average maximum width covered by the 1945 flood and its corresponding average elevation. Using the fact that the model assumes a linear variation between table entries, the approximate amount of storage removed can then be determined. Based upon an average channel top width of 1680 ft occurring at an elevation of 402 ft and an average floodplain width of 5340 ft at the 1945 flood high-water elevation (approximately 430 ft), approximately 6210 acre-ft/mile of storage was removed from the Cannelton Pool during the 1945 flood computations.

16. One important difference between all remaining runs and the calibration runs exists. In order to accurately determine the effect of a physical change in a system, one must be certain that the same volume of water enters the altered system as was input to the original system. SOCHMJ operates such that when either elevations or discharges are input as a boundary condition, the other is computed. Therefore, the computed discharges at McAlpine from the calibration runs were used as the boundary condition at McAlpine in all succeeding runs.

17. Plates 6 and 7 illustrate the effect of constructing levees along the channel throughout the Cannelton Pool on flood heights along the Ohio River. The major effect is to increase the speed of the flood wave which, in turn, results in higher elevations on the rising side and the peak and lower elevations on the recession side of the hydrograph. Figure 2 illustrates that the difference in peak elevations is less than 0.30 ft 75 miles downstream of the Cannelton Pool, i.e., in the neighborhood of Evansville.

18. Two additional runs were conducted in which the calibration values of Manning's n in the Cannelton Pool were first increased and then decreased by 20 percent. In these runs, the geometric tables continued to reflect the presence of levees along the channel. Results are presented at several points along the Ohio River in Plates 6 and 7. Essentially no difference in flood heights can be observed due to variations in Manning's n by the time Evansville is reached. Figure 3, which is a plot of the difference in peak elevations versus distance along the river, illustrates that actually the effects of the variations in Manning's n are essentially limited to locations within the Cannelton Pool.

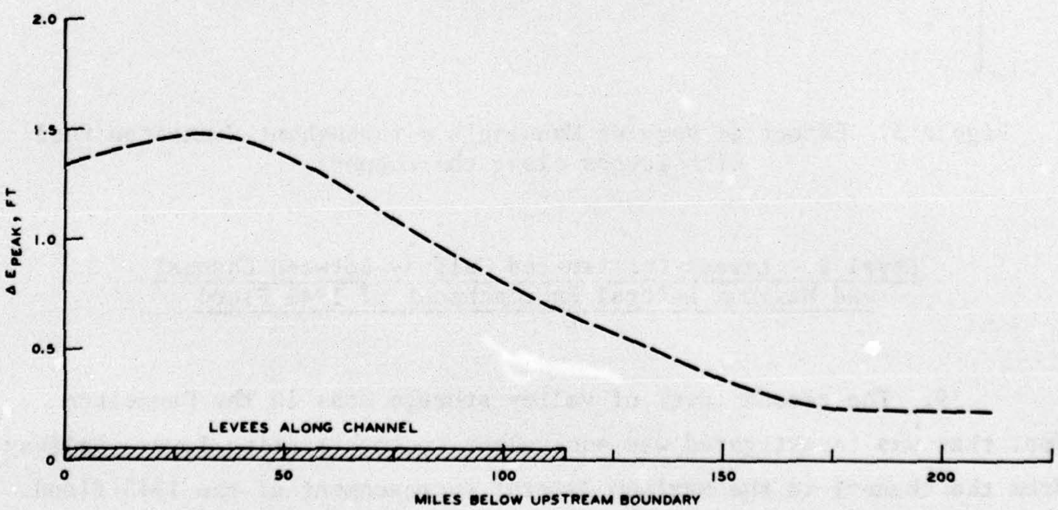

Figure 2. Effect of levees along the channel throughout the Cannelton Pool

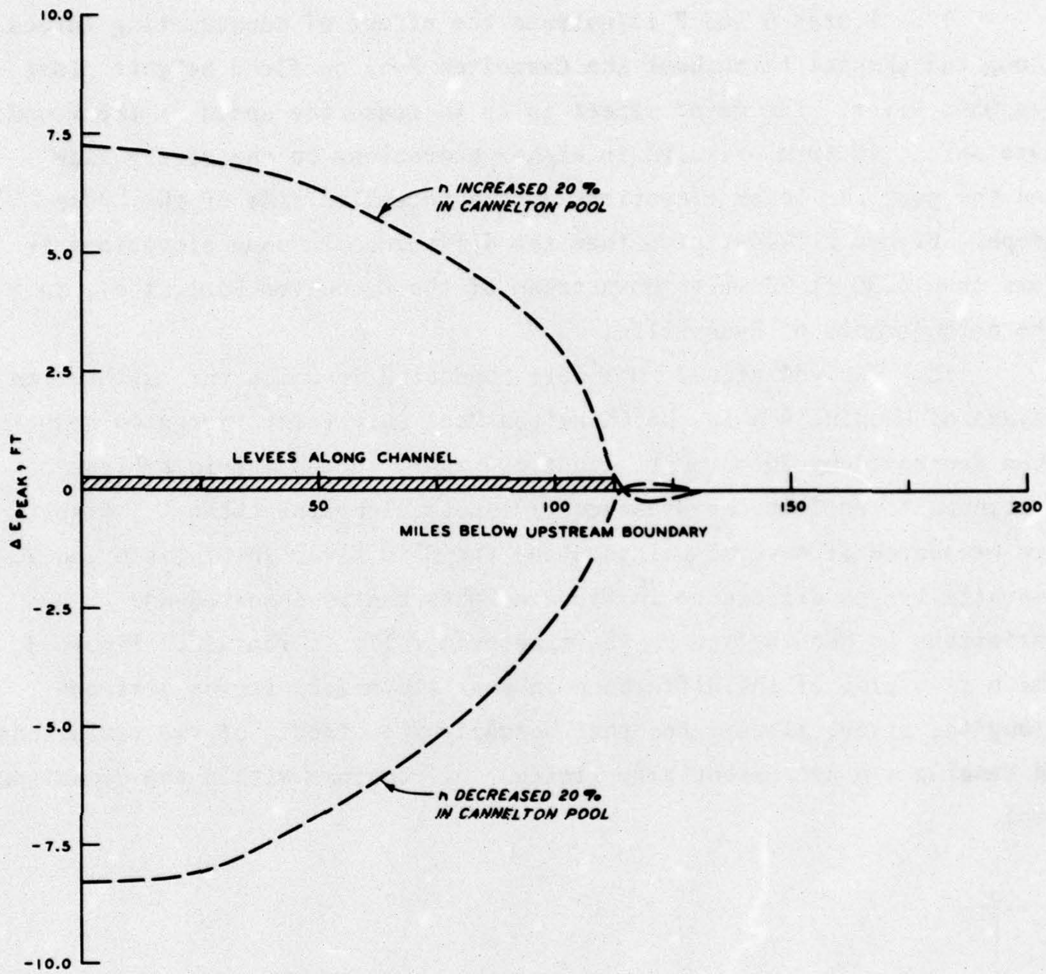

Figure 3. Effect of varying Manning's n throughout Cannelton Pool with levees along the channel

<u>Level 2 - Levees Constructed Halfway Between Channel and Maximum Lateral Encroachment of 1945 Flood</u>

19. The second level of valley storage loss in the Cannelton Pool that was investigated was equivalent to constructing levees halfway from the channel to the maximum lateral encroachment of the 1945 flood. As for the case of levees along the channel, an estimate of the storage removed can be computed. Based upon an average halfway width of 3660 ft

at the average elevation of 421 ft and the previously determined average floodplain width of 5340 ft at the 1945 flood high-water elevation of 430 ft, the storage loss is approximately 915 acre-ft/mile.

20. The model runs were set up in the same manner as those in the previous section, i.e., computed discharges from the calibration phase were input at McAlpine and each run was broken into two segments; namely, 18 February-1 March and 1 March-18 March. Also, as before, two additional runs were made in which the calibration values of Manning's n for those elevations at which the top widths were changed in the Cannelton Pool were first increased and then decreased by 20 percent.

21. Results from these runs are presented in Plates 8 and 9. As was expected, since the storage removed was much less, the effect of the halfway positioned levees on flood heights along the Ohio River was less than that in the previous application where the levees were placed along the channel. This is further illustrated in a comparison of Figures 2 and 4. Comparison of Figures 3 and 5 for the two levels of storage loss reveals little difference in the plots of change in peak elevations

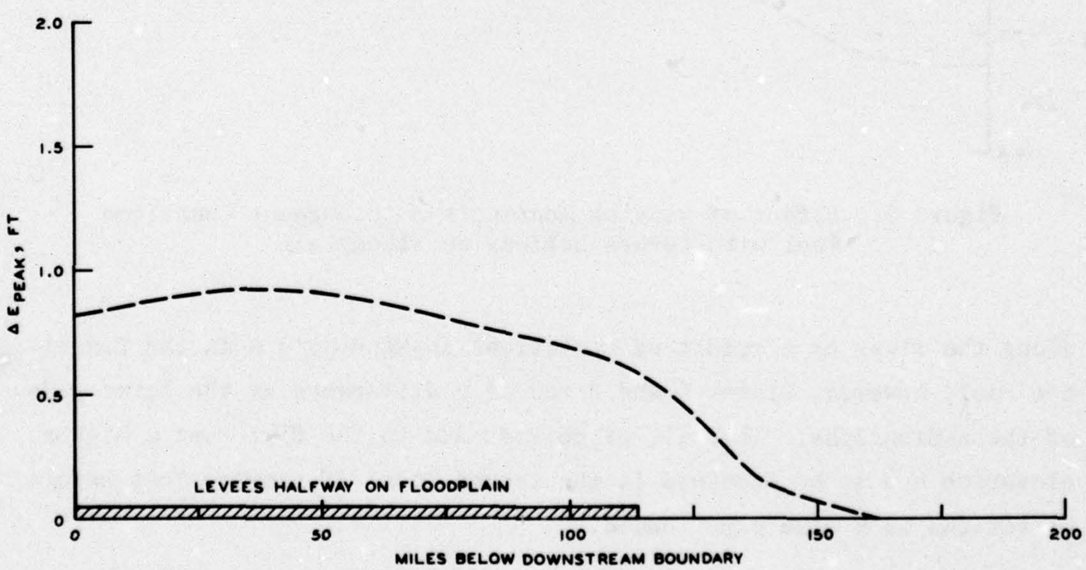

Figure 4. Effect of levees halfway on floodplain throughout Cannelton Pool

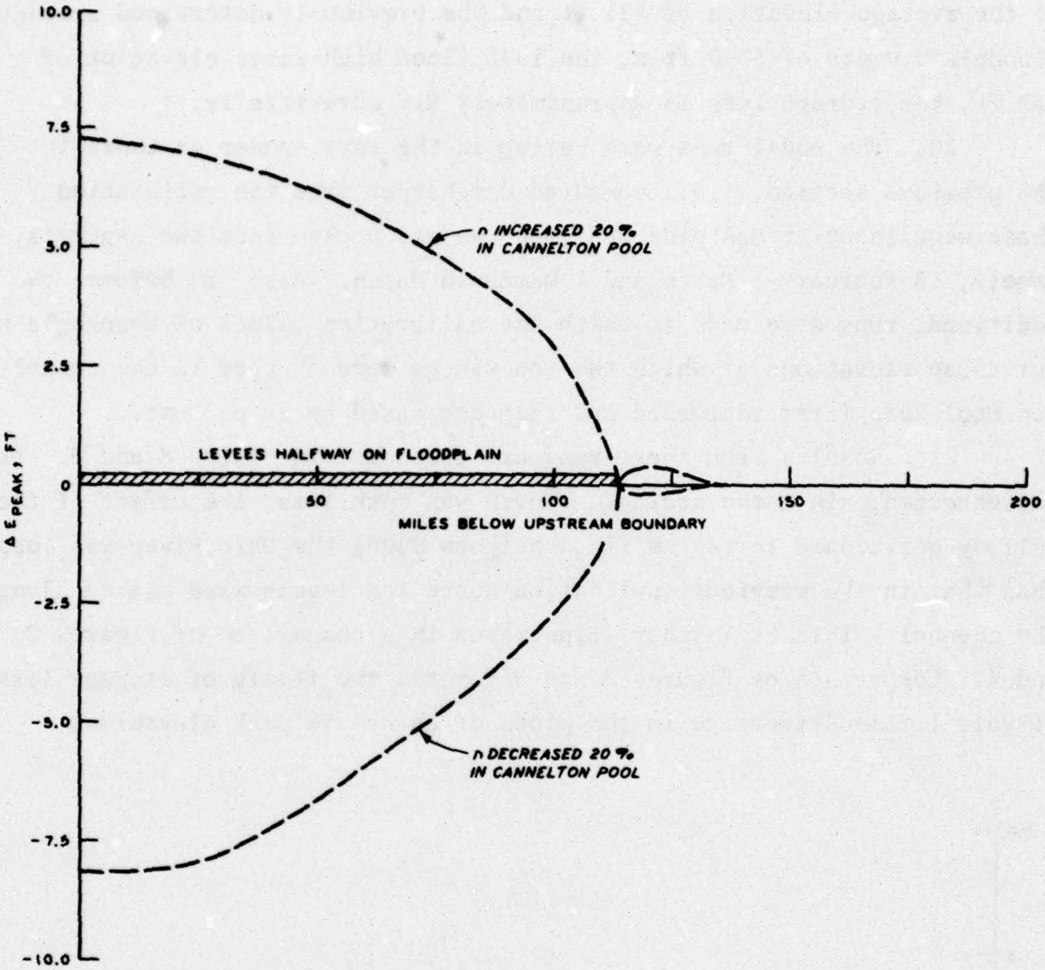

Figure 5. Effect of varying Manning's n throughout Cannelton Pool with levees halfway on floodplain

along the river as a result of variations in Manning's n in the Cannelton Pool; however, Plates 6 and 8 reveal a difference at the lower ends of the hydrographs. This is, of course, due to the fact that a higher elevation had to be attained in the second level of storage loss before variations in n were experienced.

Level 3 - Levees Constructed Along the Channel in the Lower 58 Miles of the Cannelton Pool

22. In both of the two previous levels of storage loss, the loss was assumed to occur throughout the Cannelton Pool, which extends to the upstream boundary at McAlpine Lock and Dam. Therefore, no information was obtained to answer the question of whether a loss of valley storage affected greater the upstream or downstream flood heights. Thus, an additional run in which levees were constructed along the channel in only the lower 58 miles of the Cannelton Pool was made. Results are plotted in Figure 6 and show that flood heights upstream of the reach are affected significantly more than at downstream locations. A similar result has been computed by Fread[5] concerning variations in Manning's n throughout an interior reach.

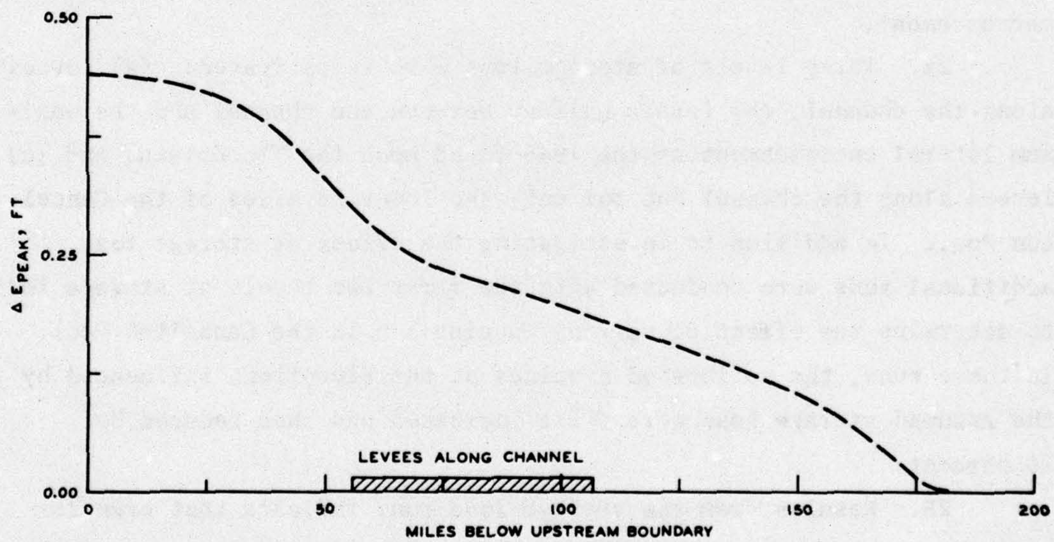

Figure 6. Effect of levees along the channel in lower 58 miles of Cannelton Pool

PART V: SUMMARY

23. The ORD-WES numerical open-channel unsteady flow model (SOCHMJ) has been employed to estimate the effect on flood heights along the Ohio River of a loss of valley storage in the Cannelton Pool. To accomplish this, SOCHMJ was calibrated to the 1945 flood before application to different levels of storage loss. Some fairly significant modifications to the description of the physical system were required to obtain a reasonable calibration because of the high flows cutting across some of the major bends between Cannelton Lock and Dam and Lock and Dam 49 (see paragraph 12). This fairly crude calibration procedure is considered reasonable for the feasibility study reported herein; however, a more rigorous treatment of these overbank flow situations may be desirable during the design phase of any proposed floodplain encroachment.

24. Three levels of storage loss were investigated: (a) levees along the channel, (b) levees halfway between the channel and the maximum lateral encroachment of the 1945 flood upon the floodplain, and (c) levees along the channel but for only the lower 58 miles of the Cannelton Pool. In addition to investigating the effect of storage loss, additional runs were conducted with the first two levels of storage loss to determine the effect of varying Manning's n in the Cannelton Pool. In these runs, the calibrated n values at the elevations influenced by the assumed storage loss were first increased and then reduced by 20 percent.

25. Results from the storage loss runs indicate that even for levees constructed along the channel, the maximum increase in flood heights is only about 1.50 ft and occurs about 30 miles below McAlpine Lock and Dam within the Cannelton Pool. It appears that the difference in peak elevations in the neighborhood of Evansville will be less than 0.50 ft for the case of levees along the channel. There will be essentially no effect for the case of levees constructed halfway from the channel to the maximum lateral encroachment of the 1945 flood.

26. Increasing Manning's n by 20 percent throughout the

Cannelton Pool resulted in a maximum increase of flood heights of about 7.0 ft, which occurred at the upstream boundary, i.e. McAlpine Lock and Dam. Decreasing Manning's n by 20 percent resulted in a maximum decrease of about 8.0 ft, again occurring at the upstream boundary. Essentially no effect was computed at locations more than 15 miles downstream of the Cannelton Pool for either an increase or decrease in Manning's n.

27. Conducting a run in which only the lower 58 miles of the Cannelton Pool had valley storage removed demonstrated that the effect on flood heights of a loss of valley storage in a reach is greater upstream of the reach than downstream.

28. It can be concluded from these results that a loss of valley storage in the Cannelton Pool will increase the speed of the flood wave and thus result in higher flood heights within the Cannelton Pool on the rising side and at the peak of the hydrograph; however, little effect will be noticed at locations as far downstream as Evansville.

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Table 1

Discretization of the Physical System

Branch	Location	Δx, miles	No. of Δx's
1	McAlpine L&D - RM+ 320.9	4.675	12
2	RM 320.9 - Cannelton L&D	5.017	12
3	Cannelton L&D - RM 233.0	4.617	6
4	RM 233.0 - Newburgh L&D	4.617	6
5*	Newburgh L&D - Green R.	2.025	4
6	Green River	5.933	12
7	Green R. - Uniontown L&D	5.150	12
8*	Uniontown L&D - Wabash R.	0.600	4
9	Wabash River	13.920	6
10	Wabash R. - Smithland L&D	5.007	14
11*	Smithland L&D - Cumberland R.	1.005	4
12	Cumberland River	4.597	6
13	Cumberland R. - Tennessee R.	3.320	4
14	Tennessee River	3.593	6
15*	Tennessee R. - L&D 52	0.750	4
16	L&D 52 - Mississippi R.	5.325	8
17	Upper Miss. R.	5.237	10
18	Lower Miss. R.	4.992	24

+ Miles above junction of Ohio and Mississippi Rivers.
* Small branches.

Table 2

Rating Curve Employed at Caruthersville*

Elevation ft msl	Discharge cfs
255.0	200,000
257.0	320,000
259.0	440,000
261.0	575,000
263.0	700,000
265.0	820,000
267.0	940,000
269.0	1,050,000
271.0	1,170,000
273.0	1,290,000
275.0	1,410,000
277.0	1,550,000
279.0	1,710,000
281.0	1,920,000
283.0	2,240,000
285.0	2,900,000

* Obtained from data provided by the U. S. Army Engineer District, Memphis.

Table 3

Removal of River Bends

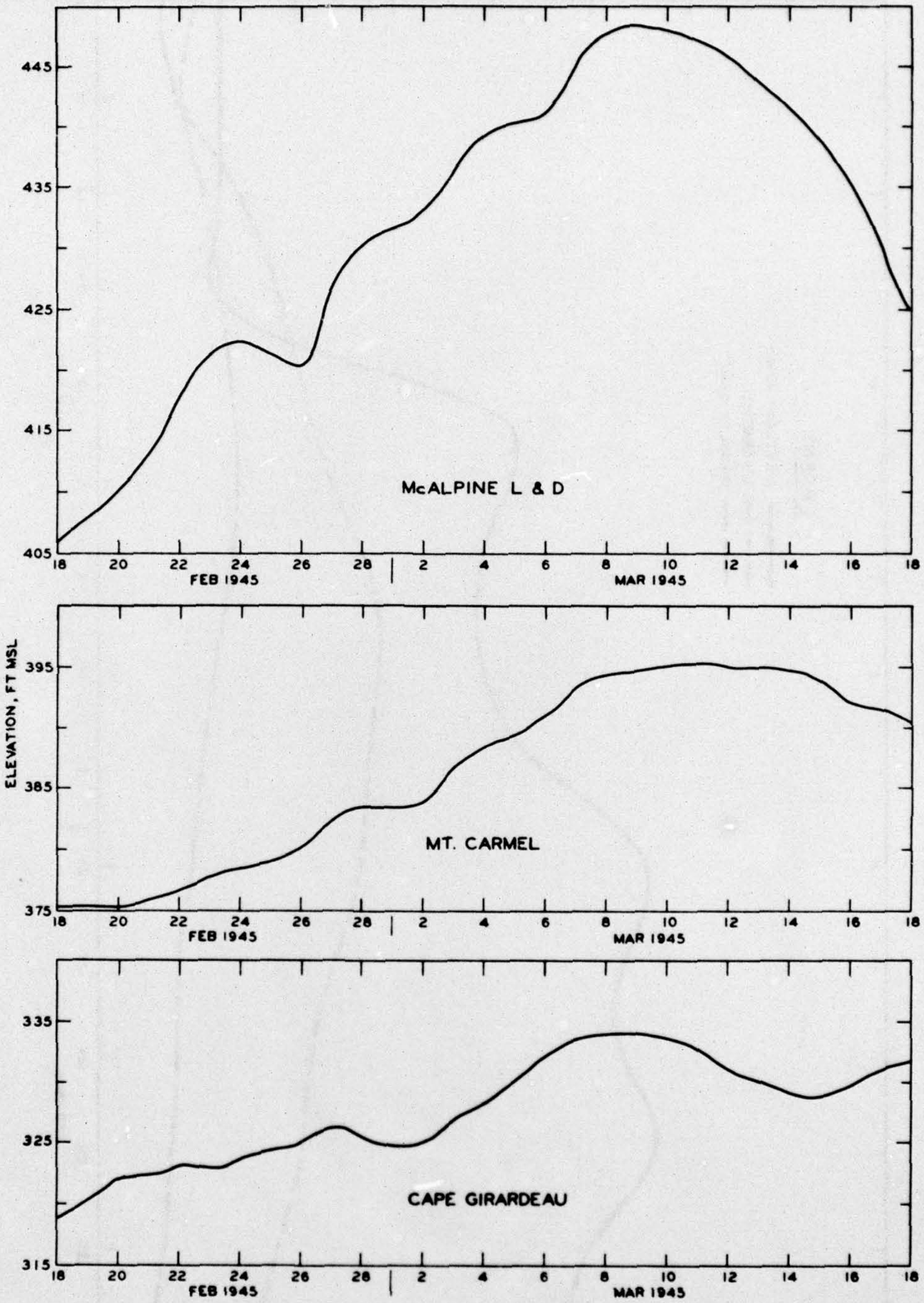
From	To	River Mileage Subtracted
721.0*	724.0	0.90
731.0	736.0	1.70
744.0	748.0	0.80
752.0	760.0	4.00
761.0	765.0	0.80
777.0	782.0	0.90
788.0	800.0	10.30
800.0	803.0	0.50
807.0	818.0	4.80
821.0	826.0	0.90
826.0	831.5	2.10
837.0	840.0	0.70
841.0	844.5	1.30

* Miles below Pittsburgh, Pennsylvania.

Table 4

Discretization of Physical System After Removal of River Bends

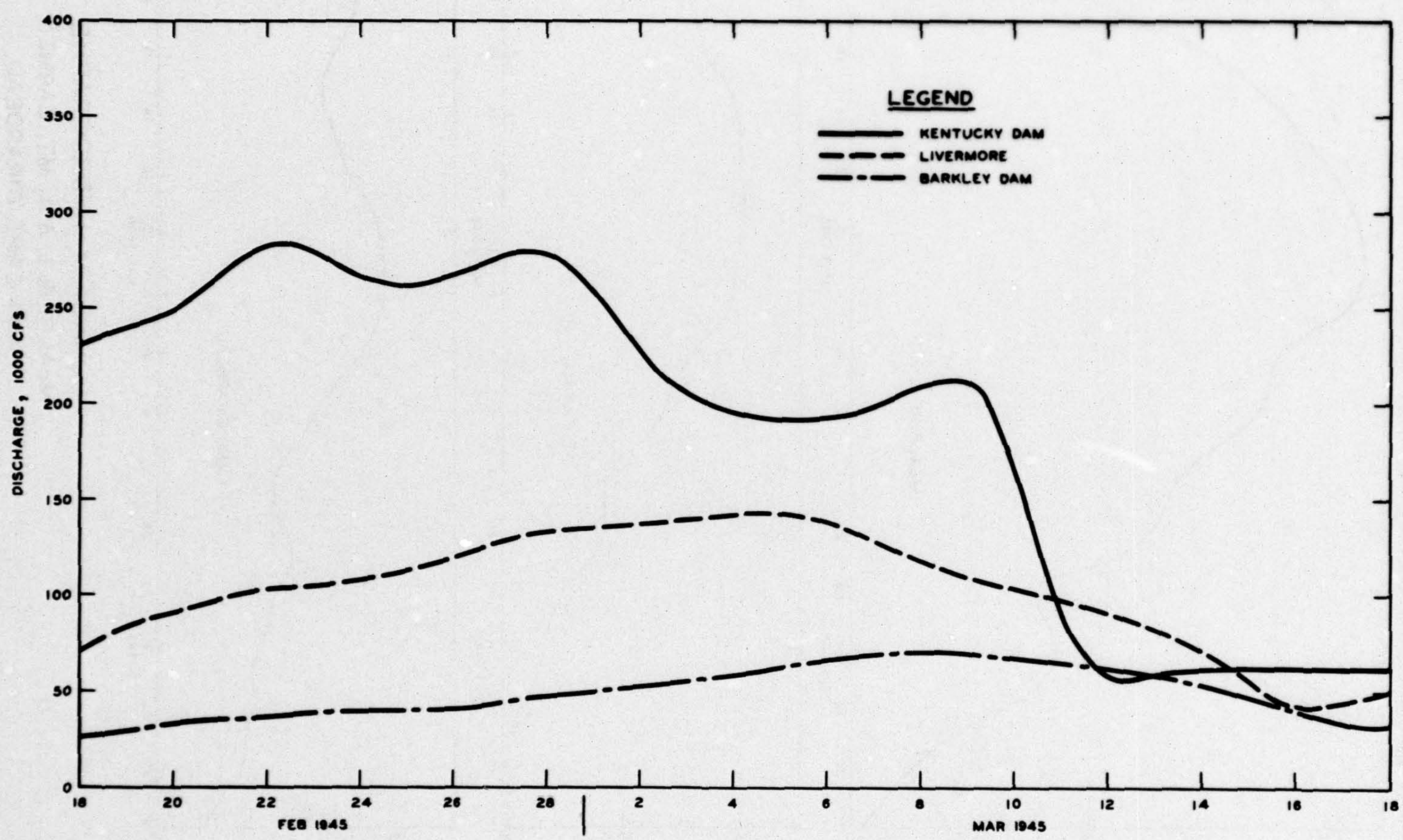
Branch	Old Δx, miles	New Δx, miles	No. of Δx's
1	4.675	4.675	12
2	5.017	5.017	12
3	4.617	4.050	6
4	4.617	3.817	6
5	2.025	1.800	4
6	5.933	5.933	12
7	5.150	3.433	12
8	0.600	0.600	4
9	13.920	13.920	6
10	5.007	5.007	14
11	1.005	1.005	4
12	4.597	4.597	6
13	3.320	3.320	4
14	3.593	3.593	6
15	0.750	0.750	4
16	5.325	5.325	8
17	5.237	5.237	10
18	4.992	4.992	24



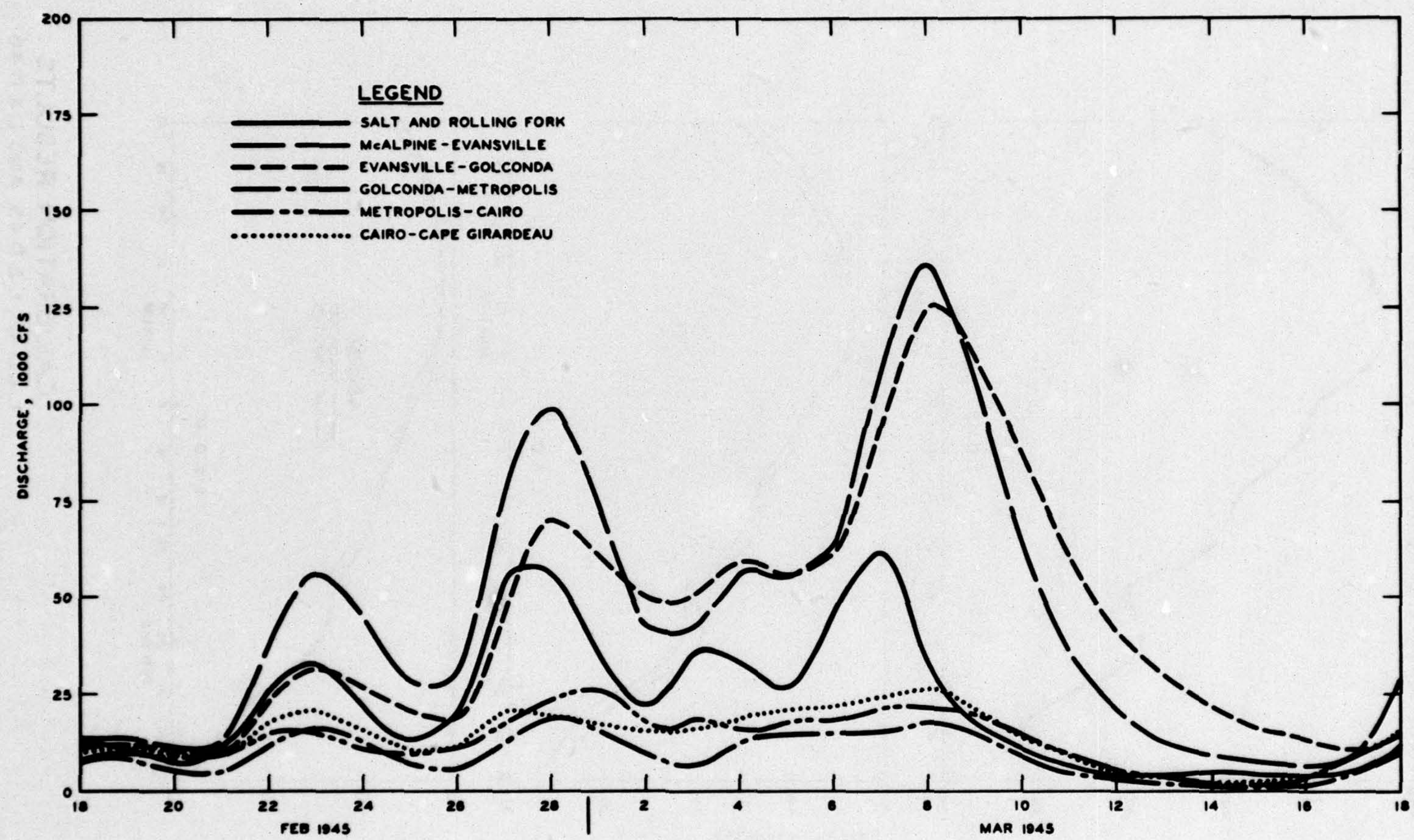
BOUNDARY HYDROGRAPHS
McALPINE L & D, MT. CARMEL
AND CAPE GIRARDEAU

PLATE 1

PLATE 2

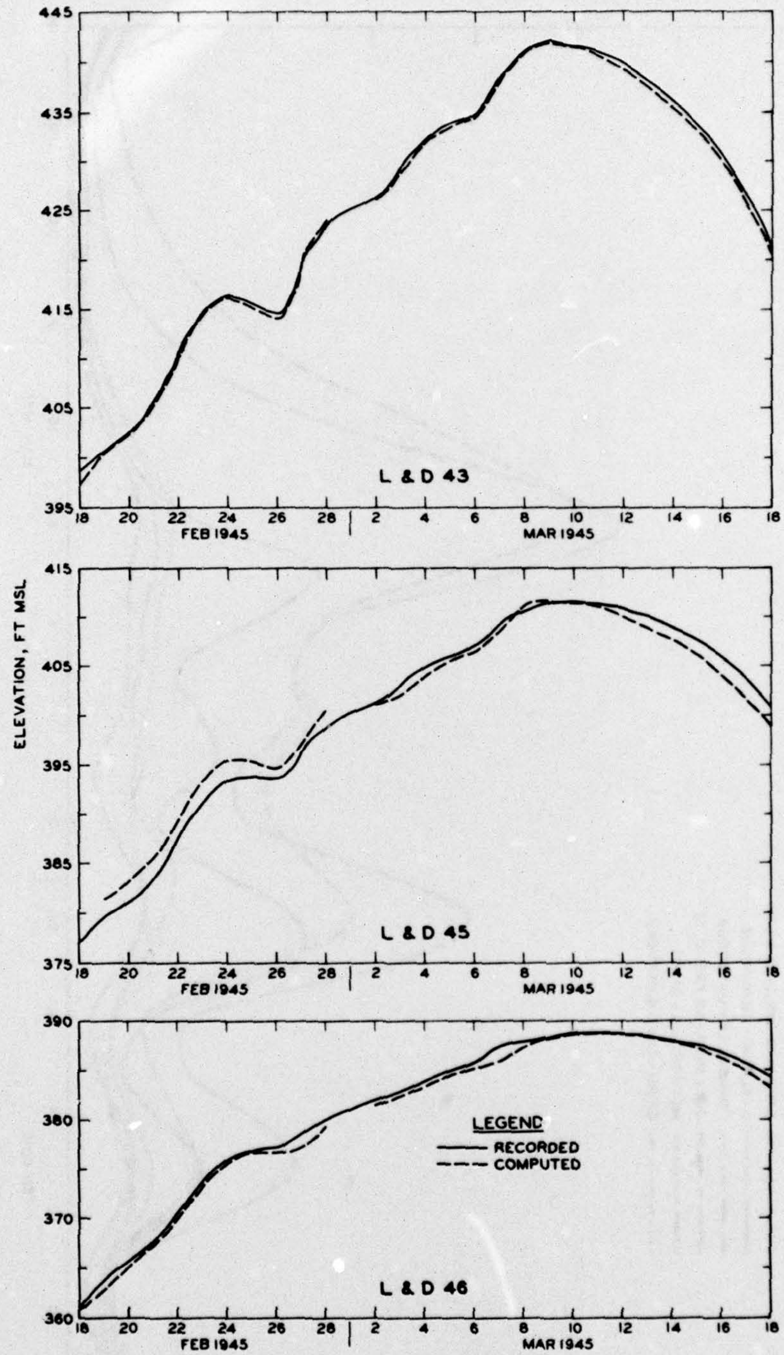


BOUNDARY HYDROGRAPHS



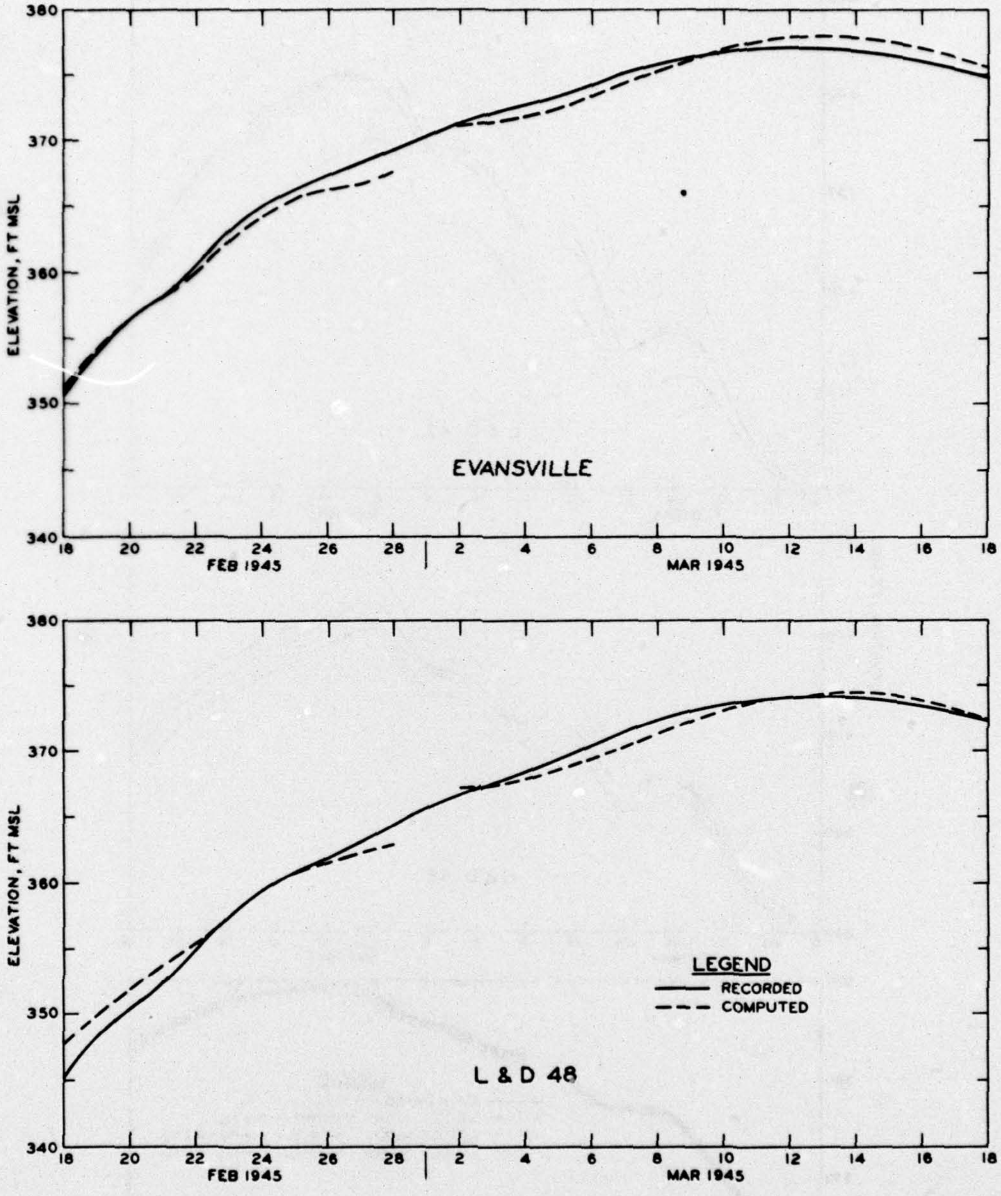
LATERAL INFLOWS

PLATE 3

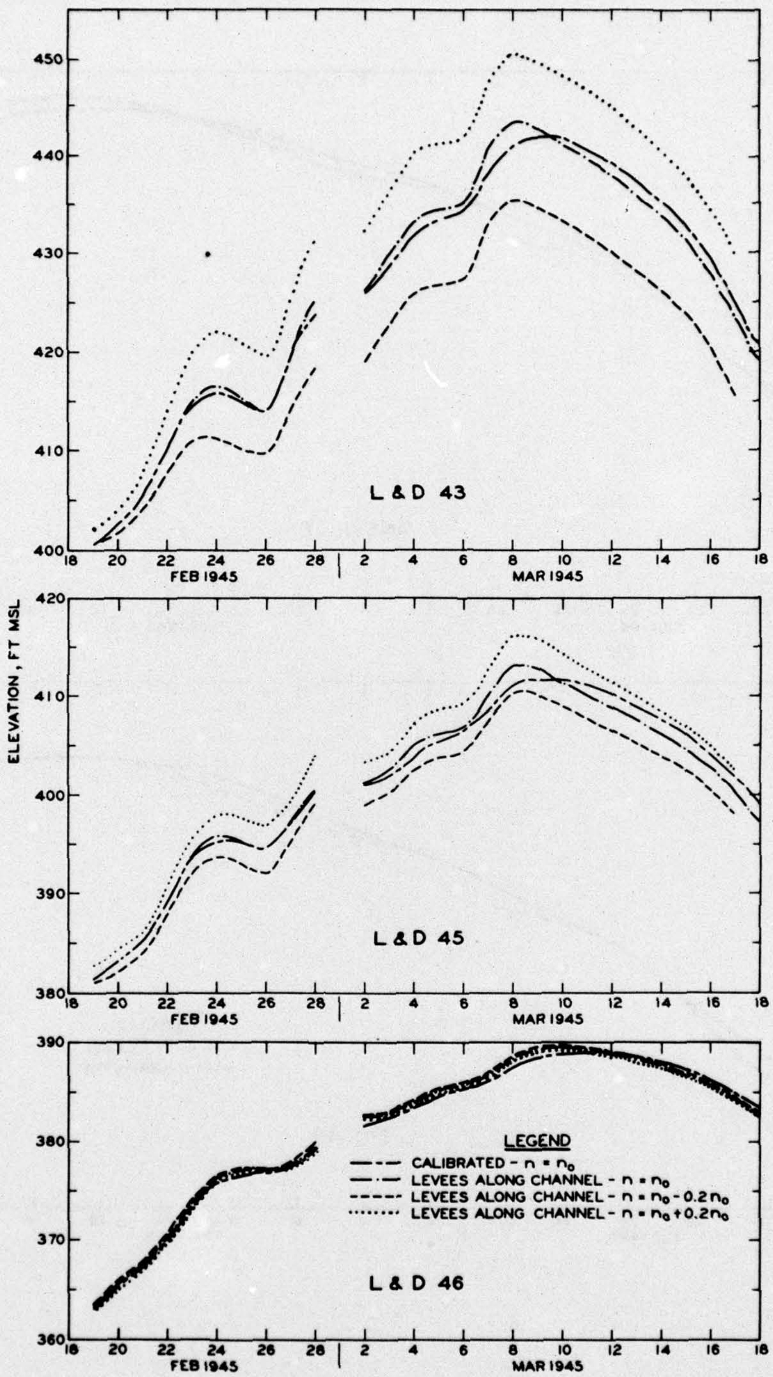


CALIBRATION RESULTS
L & D 43, L & D 45, AND L & D 46

PLATE 4

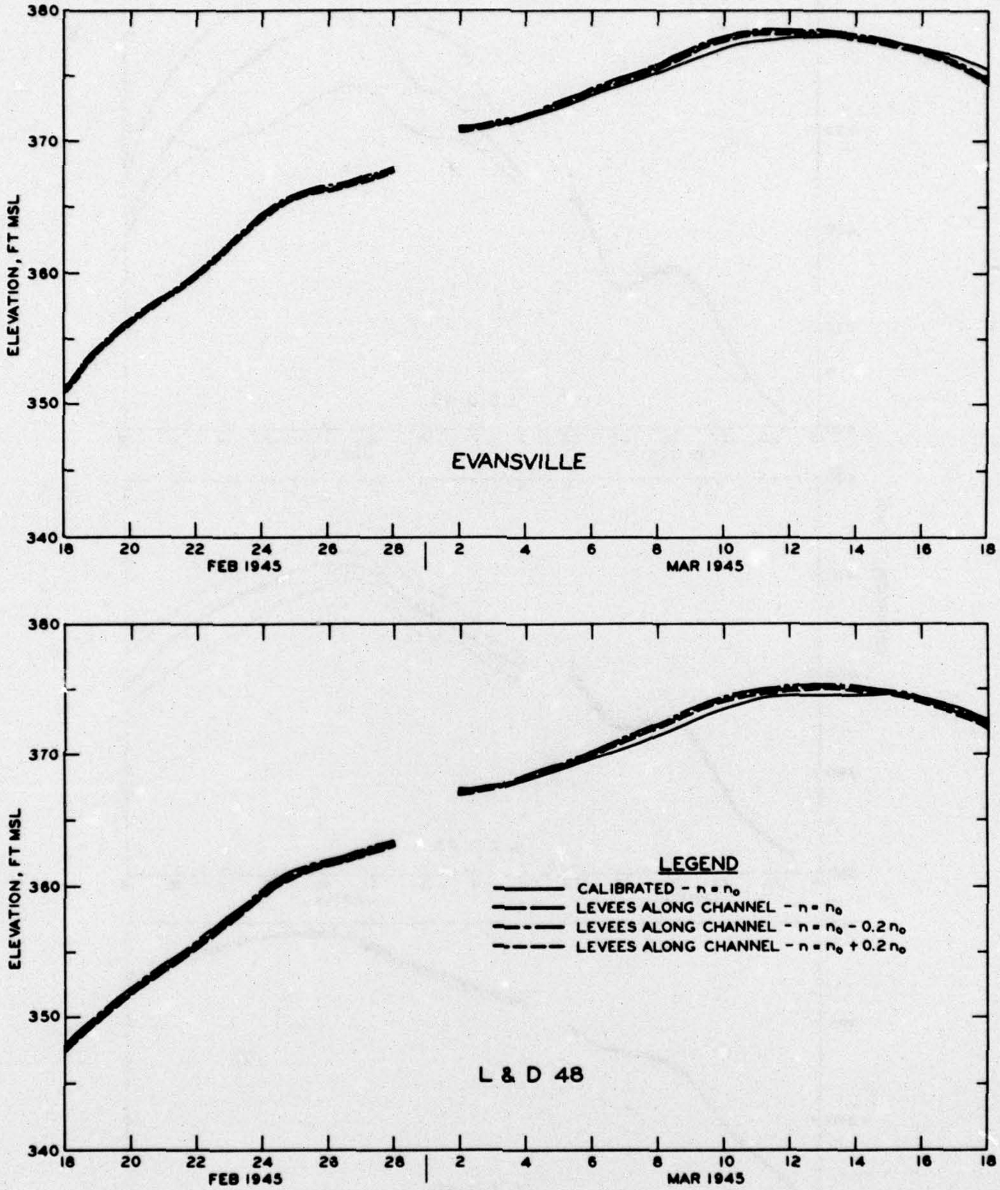


CALIBRATION RESULTS
EVANSVILLE AND L & D 48



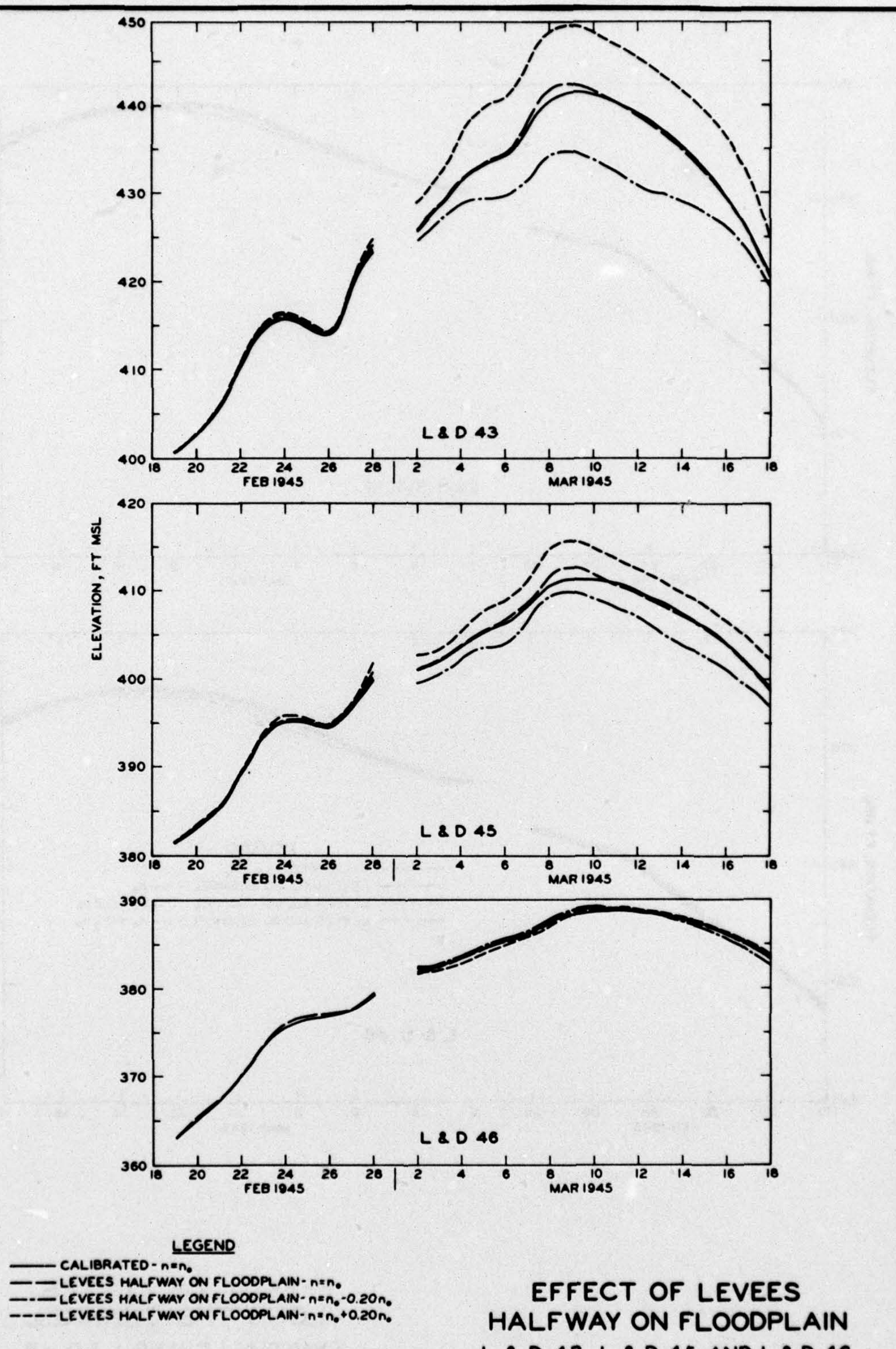
EFFECT OF LEVEES
ALONG THE CHANNEL
L & D 43, L & D 45, AND L & D 46

PLATE 6



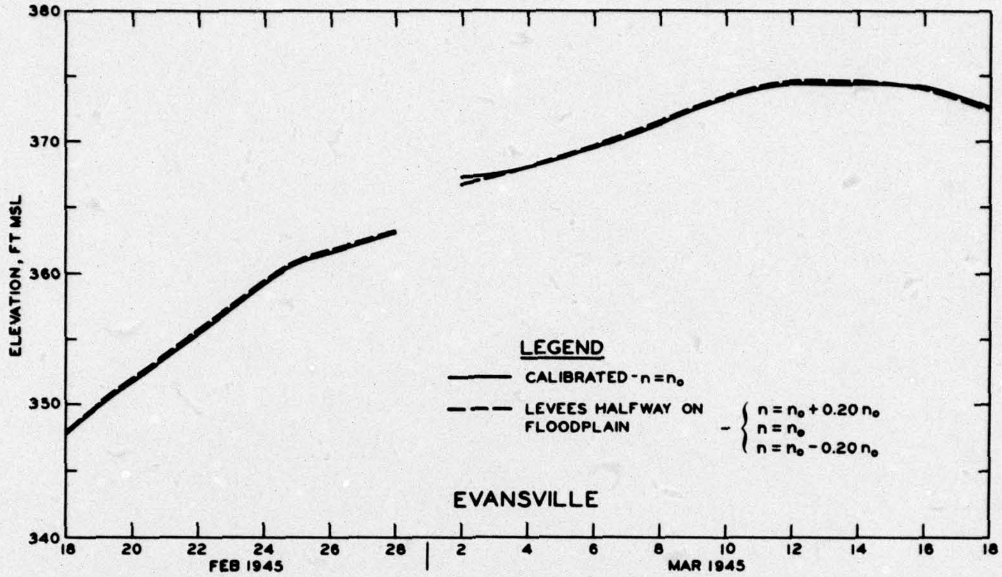
EFFECT OF LEVEES
ALONG THE CHANNEL
EVANSVILLE AND L & D 48

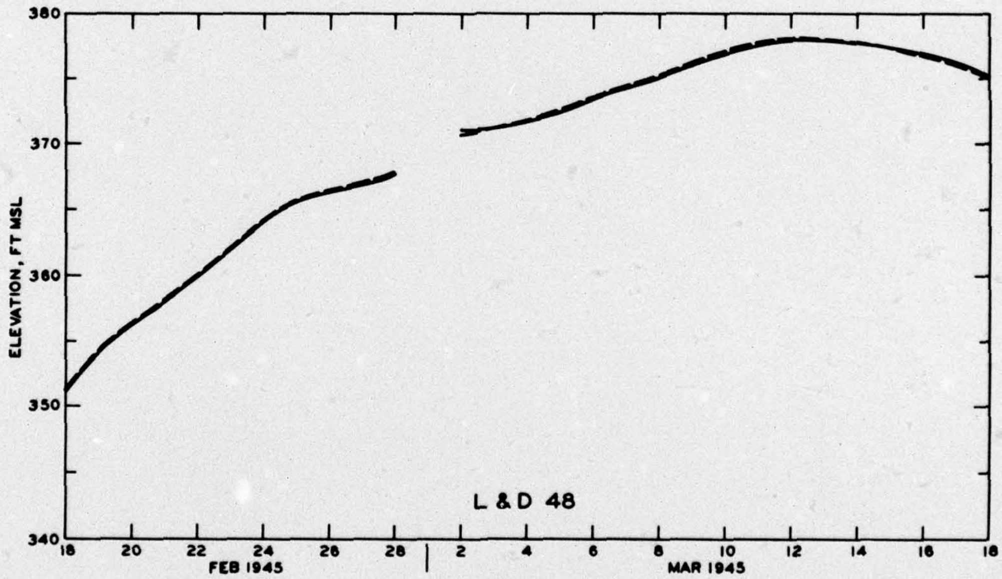
PLATE 7



EFFECT OF LEVEES HALFWAY ON FLOODPLAIN
L & D 43, L & D 45, AND L & D 46

PLATE 8





EFFECT OF LEVEES
HALFWAY ON FLOODPLAIN
EVANSVILLE AND L & D 48

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

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Effect of loss of valley storage in the Cannelton Pool on Ohio River flood heights, by Billy H. Johnson [and] Paul K. Senter. Vicksburg, U. S. Army Engineer Waterways Experiment Station, 1977.
1 v. (various pagings) illus. 27 cm. (U. S. Waterways Experiment Station. Miscellaneous paper H-77-7)
Prepared for U. S. Army Engineer Division, Ohio River, Cincinnati, Ohio.
Includes bibliography.

1. Cannelton Pool. 2. Flood control. 3. Flood waves. 4. Mathematical models. 5. Ohio River. 6. Open channel flow. 7. Storage loss. 8. Valleys. I. Senter, Paul K., joint author. II. U. S. Army Engineer Division, Ohio River. (Series: U. S. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper H-77-7)
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